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Steam turbine with 0.9X vibrations

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Piotr holds M.Sc. in engineering from Technical University in Gdansk/Poland (1991) and D.Sc. in engineering from AGH University of Science and Technology in Krakow/Poland (1998).

Abstract

This 15 MW steam turbine/gearbox/4-pole generator train, following a recent overhaul, was showing unusual phenomenon of high level 0.9X vibration during shutdown, as well as power limits due to vibration level increase. The case describes a single day* field investigation program, that lead to identification of the root cause of the problem and pin pointed other problems with the quality of the overhaul. Vibration data are reviewed showing solution through application of standard** methodology.

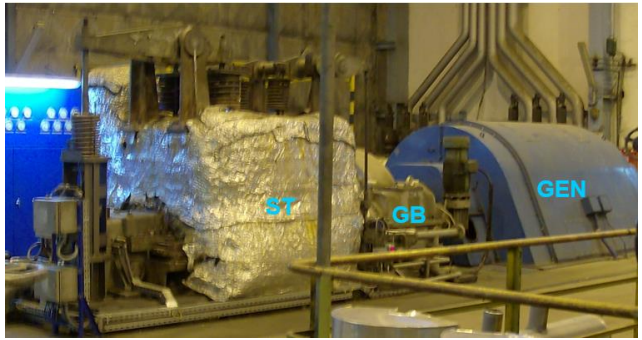
*Limitation defined by End User due to production needs.

**Standard methodology of service organization the author is working for.

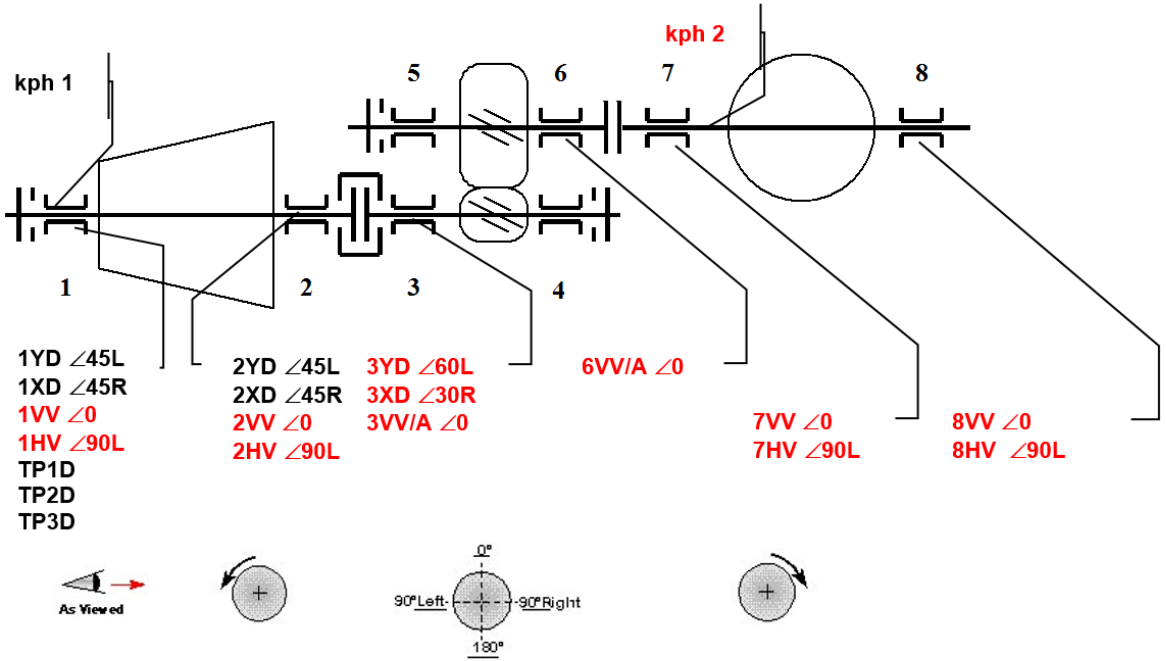
Problem

- After a recent OH, the turbine could not be loaded to more than 10MW due to a trip on high levels of shaft vibration.
- During each shutdown the machine would show extreme levels of shaft vibration accompanied by an unusual ~0.9X component dominating.
- The field investigation should be limited to one day (due to production plans).
- The expected result is “actionable information” to define corrective action(s).

Measurements



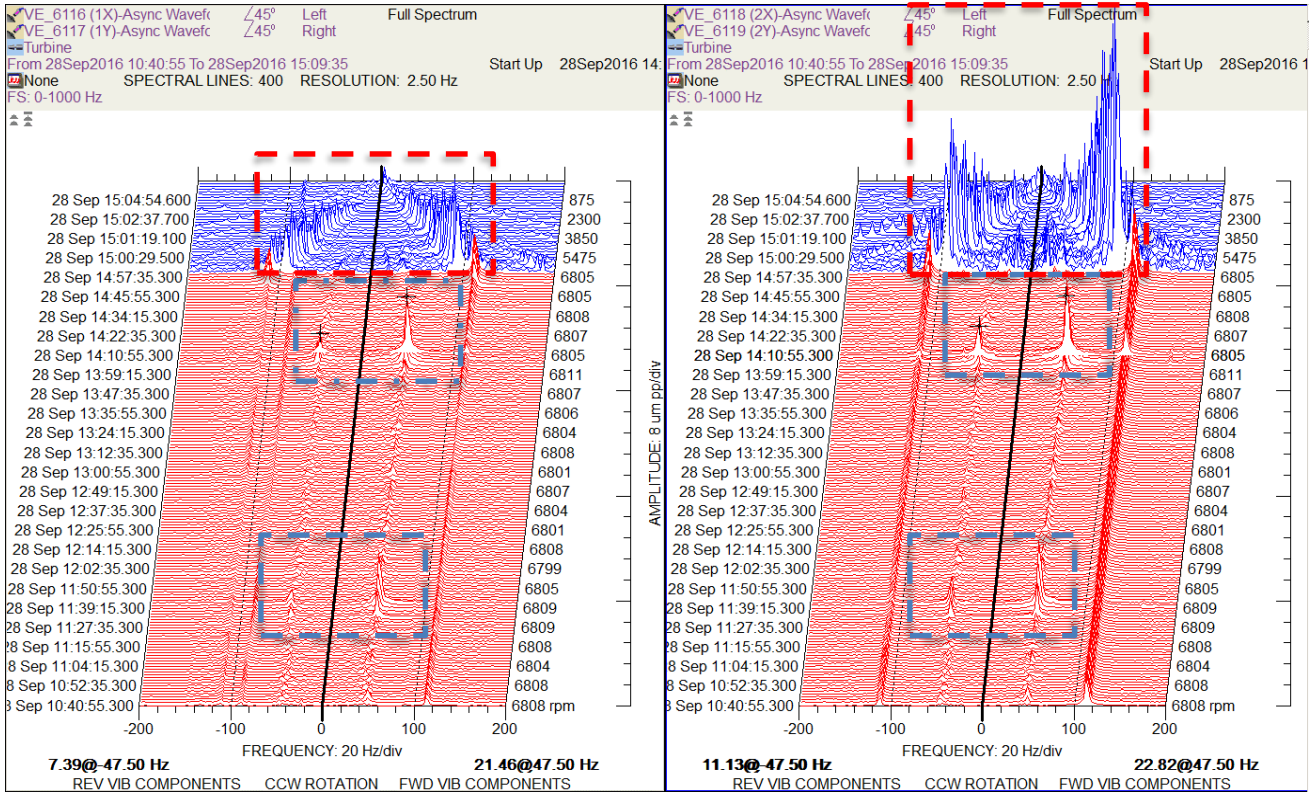
Legend:
kph – speed/phase reference (keyphasor)
D – displacement (proximity probe)
V- velocity transducer
V/A- velocity/acceleration transducer
TP – thrust position
black – permanent monitoring system
red – installed for a test



Shaft vibration at turbine bearings #1& #2

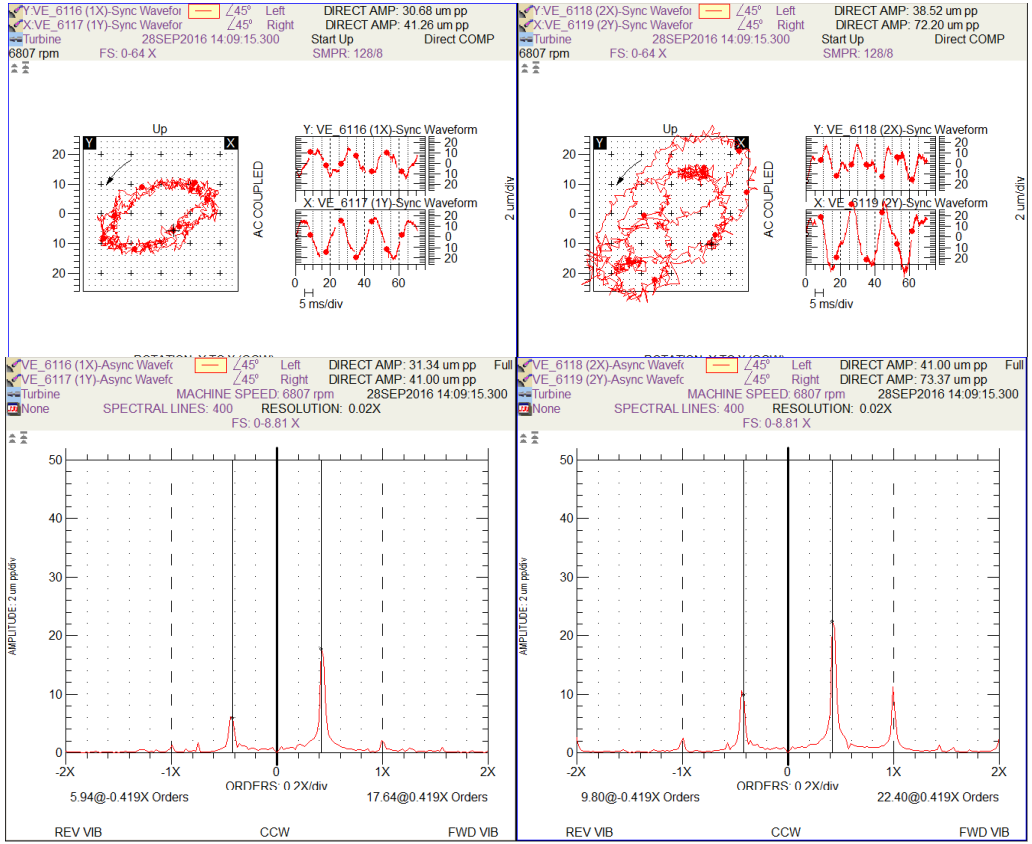
~0.4X vibration on load increase (10MW threshold)

~0.9X vibration at the shutdown

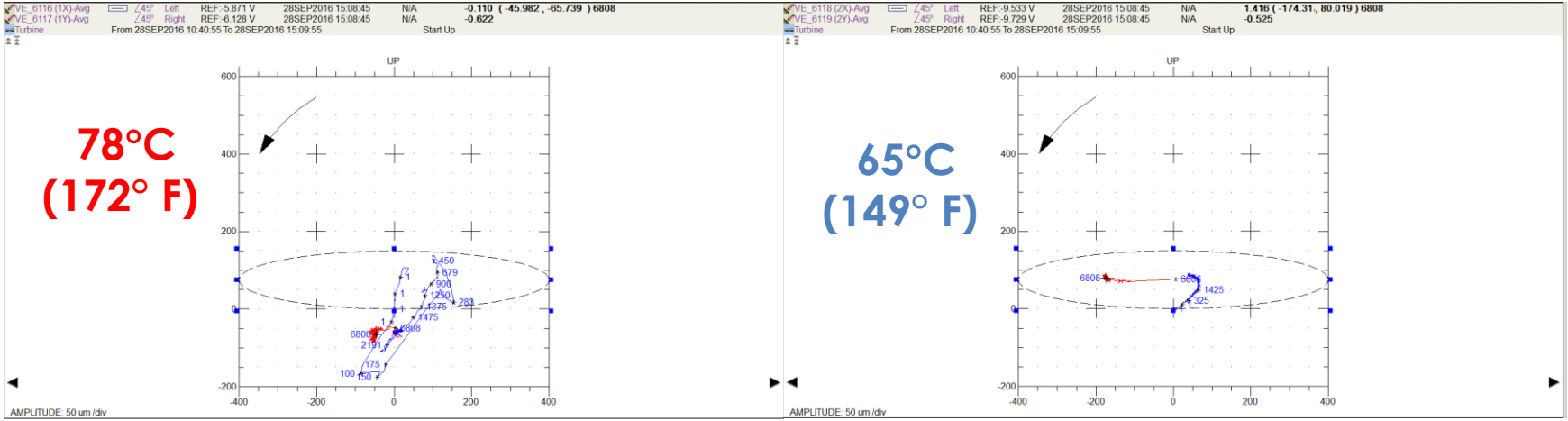


Turbine shaft orbits during load increase

- Subsynchronous
- Forward precession
- Coinciding with rotor resonance frequency…



Turbine bearings shaft centerline (SCL) plots



Note the proportions of bearing clearances. The elliptical bearing with high ellipticity (high geometrical preload) is local remedy to stability problems. Sometimes referred as “hyper-elliptical” design.

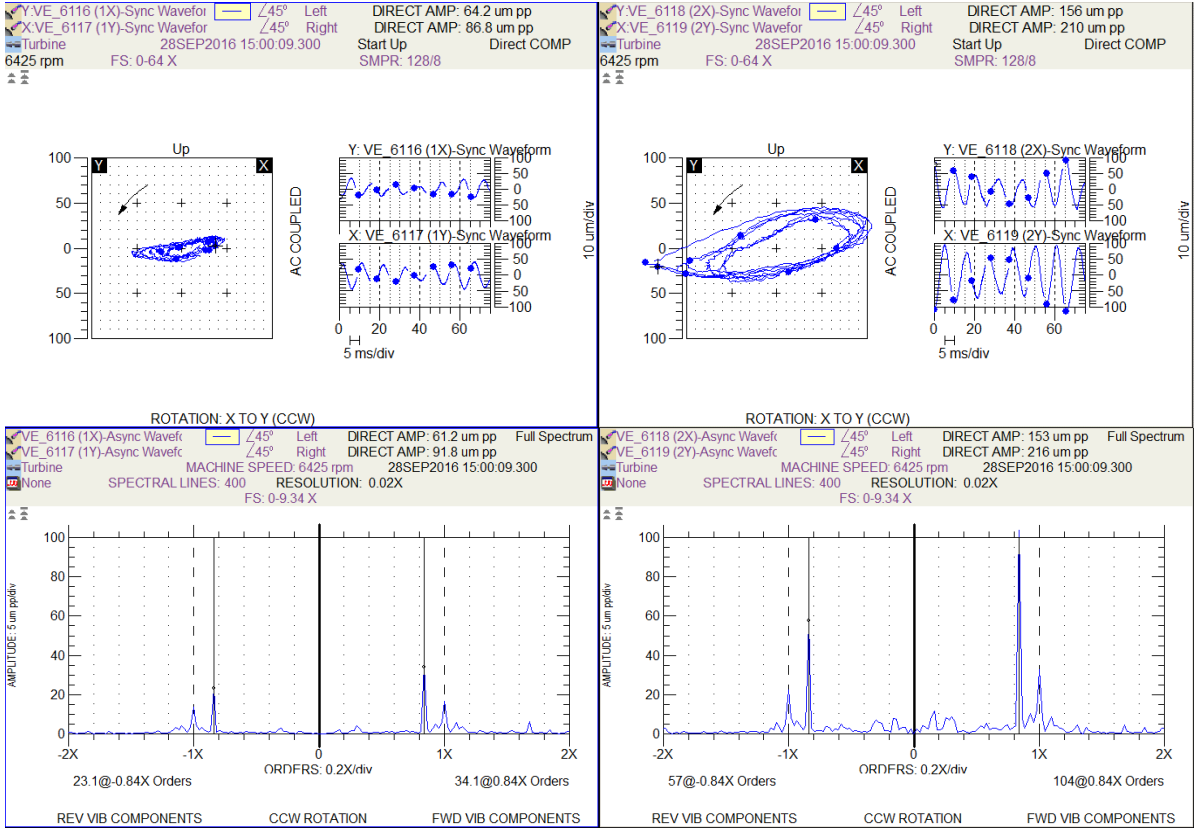
Interim analysis

- Fluid induced instability (steam whirl) onset above 10MW. Known historical problem controlled by "hyper-elliptical" bearing design.
- Deterioration of bearing properties due assembly errors and/or high vibration events led to lowering of stability threshold.
- Suspected:
  - Bearing #1 overloaded, clearance reduced, possibly bearing tilted.
  - Bearing #2 "crush" reduced. And asymmetric clearances in the steam labyrinth seals.

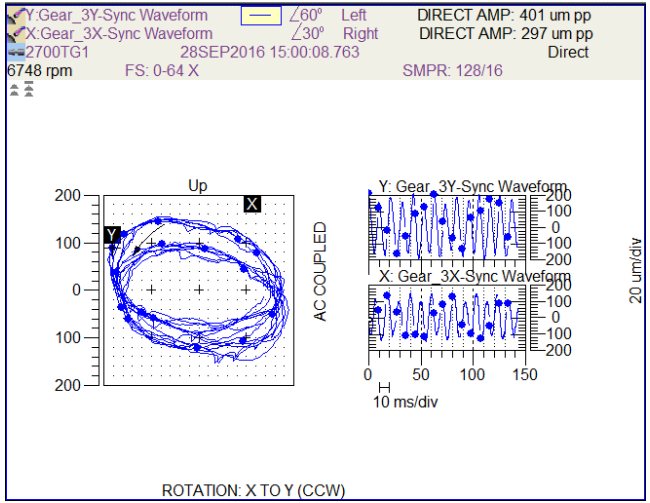
No relation with the 0.9X during shutdowns…

Turbine brg. orbits as shutdown commences

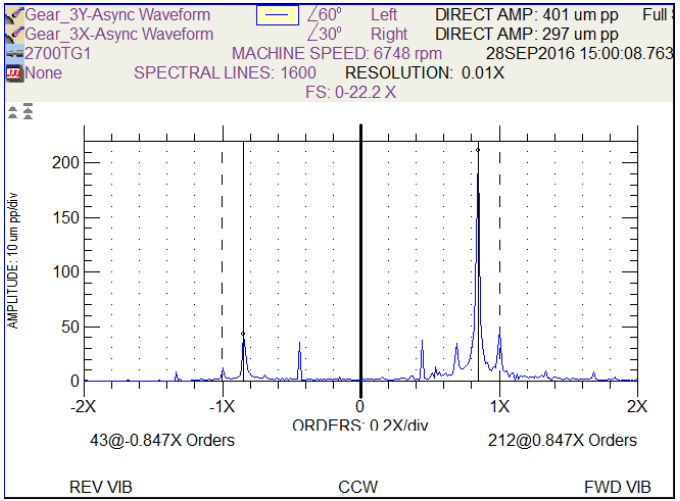
- Subsynchronous
- Forward precession
- Preloaded shape
- Unusual frequency ~ 0.9X

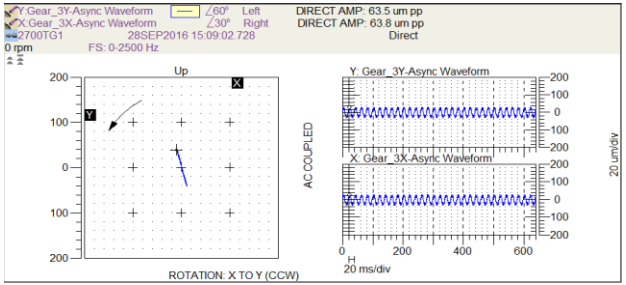


Brg. #3 (pinion) vibration



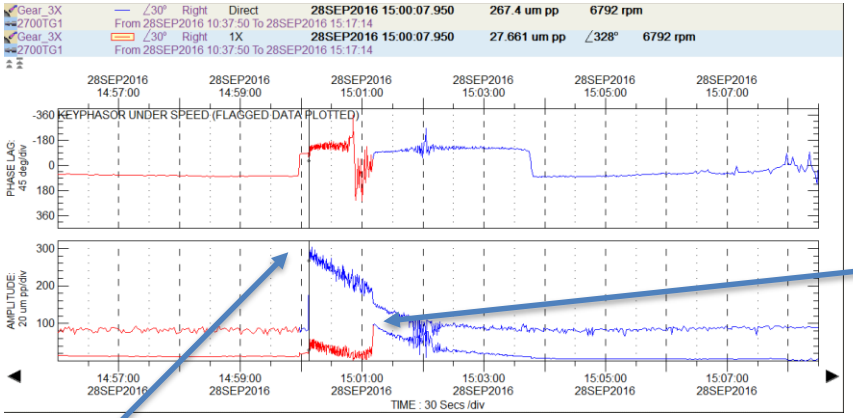
Elliptical subsynchronous component, some 1X…





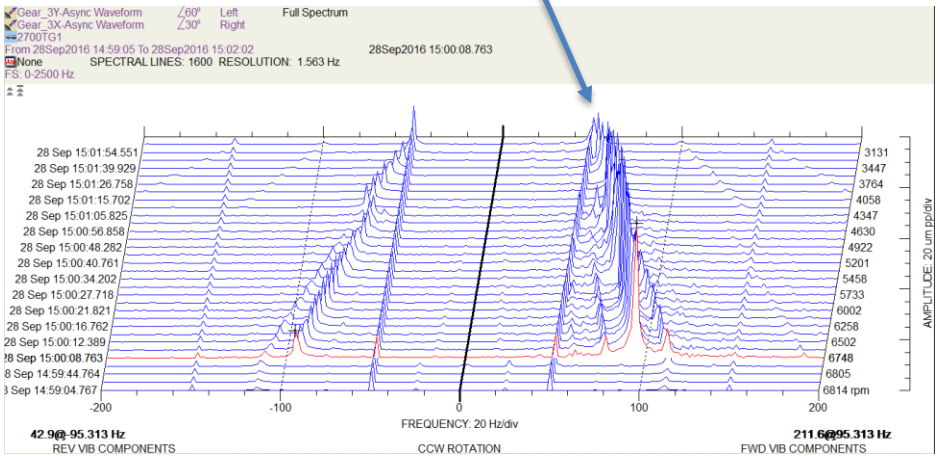
and 50Hz electrical noise (measured at stopped machine).

Brg. #3 (pinion) vibration



Vibration starts at the moment of shutdown

Subsynchronous merges to 1X at ~ 4200 rpm



Short list of (un)usual suspects

- Fluid in the central bore?
- Torsional excitation from generator?
- Unusual type of fluid induced instability in the pinon bearing(s)?

Hyp. #1: Fluid trapped in central bore

Trapped oil or water could create subsynchronous component, forward in precession, close to 1X.

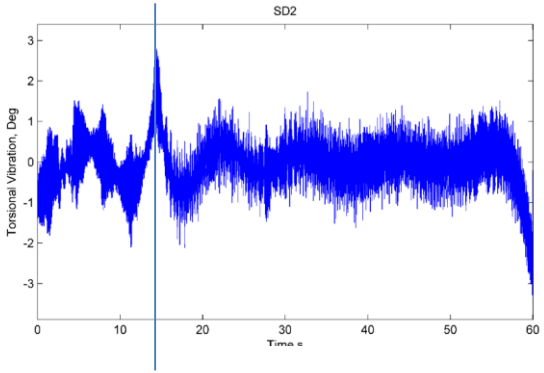
- Why does it appear only at the beginning of shutdown?
- Rotor and coupling lack any bore…

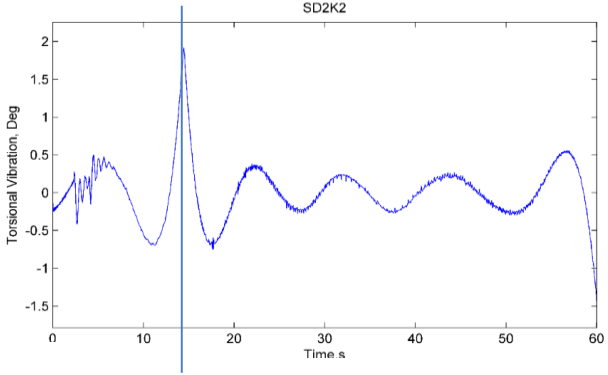
Hypothesis #1 – not probable

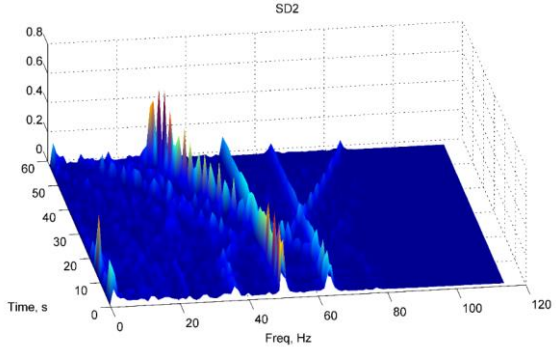
Hyp. #2: Torsional excitation from generator

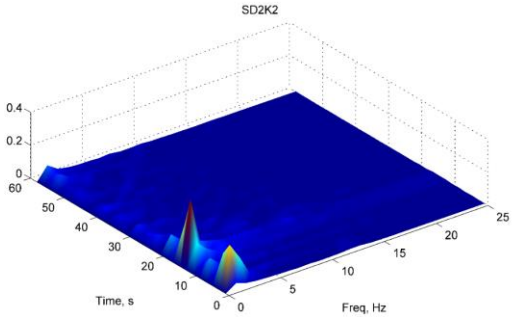
- This is 4-pole generator with nominal speed 1500 rpm. So the 4X for generator rotor (6000 cpm) is 0.88X for turbine rotor operating 6805 rpm.
- The unit is shut down from reverse power signal.
- Can the generator remain partially excited during shutdown? The delays on reverse power detection were recently increased.

Torsional vibration measurements







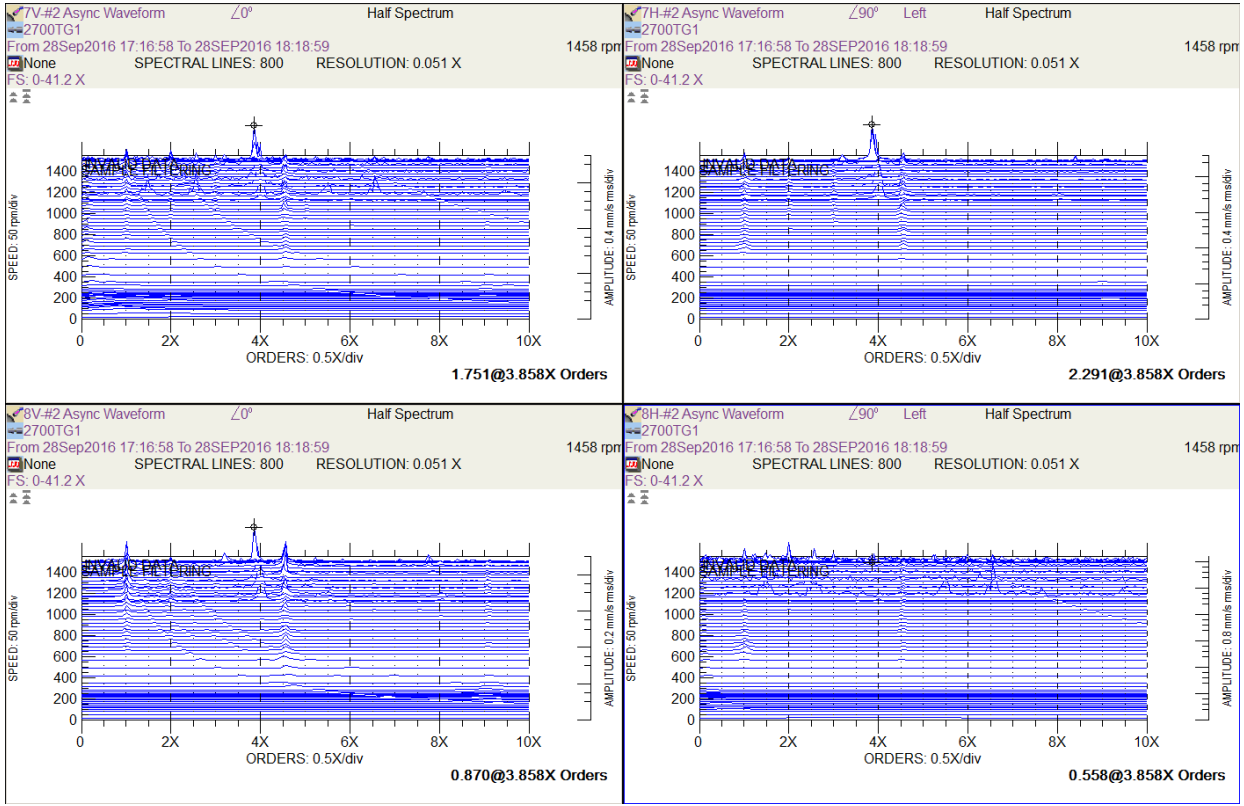


Time interval method (TIM) used for keyphasor events.

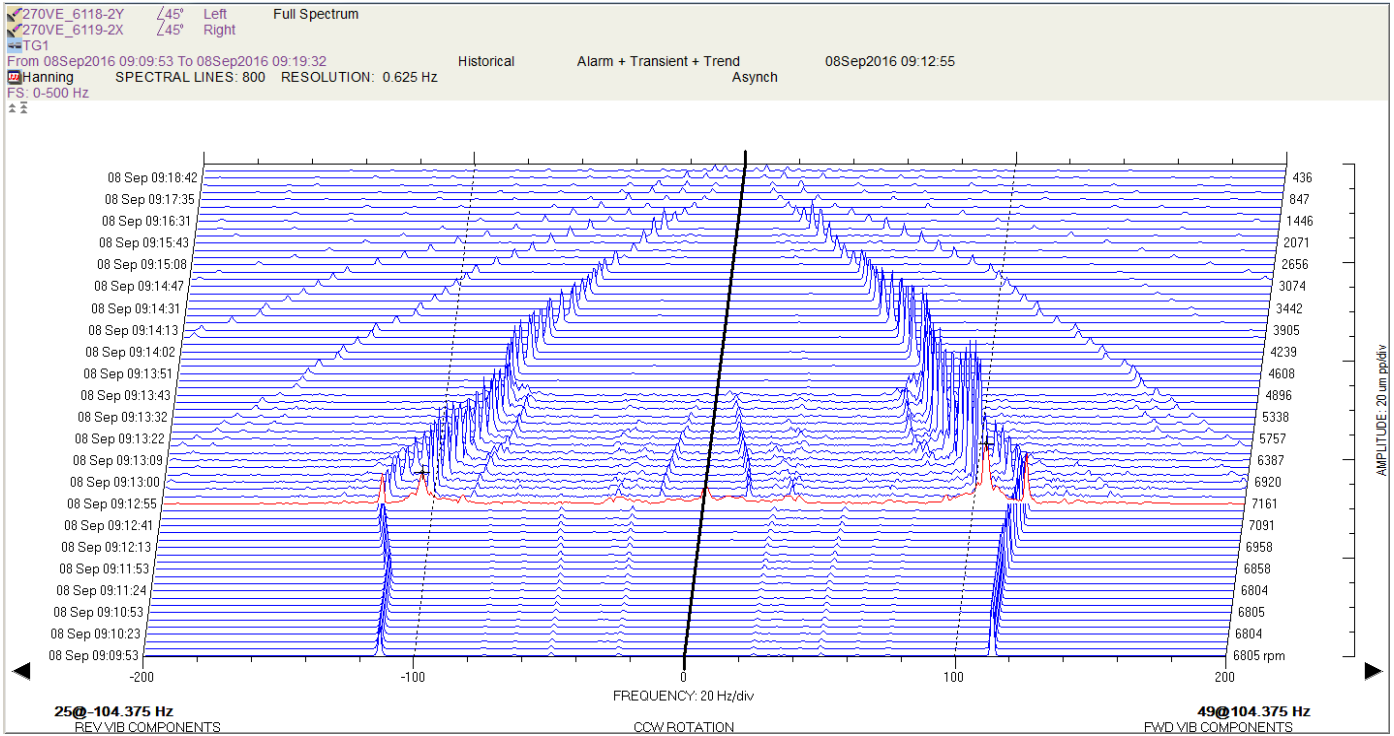
No torsional activity for ~0.1X (an alias for ~0.9X).

In addition, based on casing vibration

The frequency of excited vibration is <u>not</u> generator 4X.



In addition, from historical overspeed test



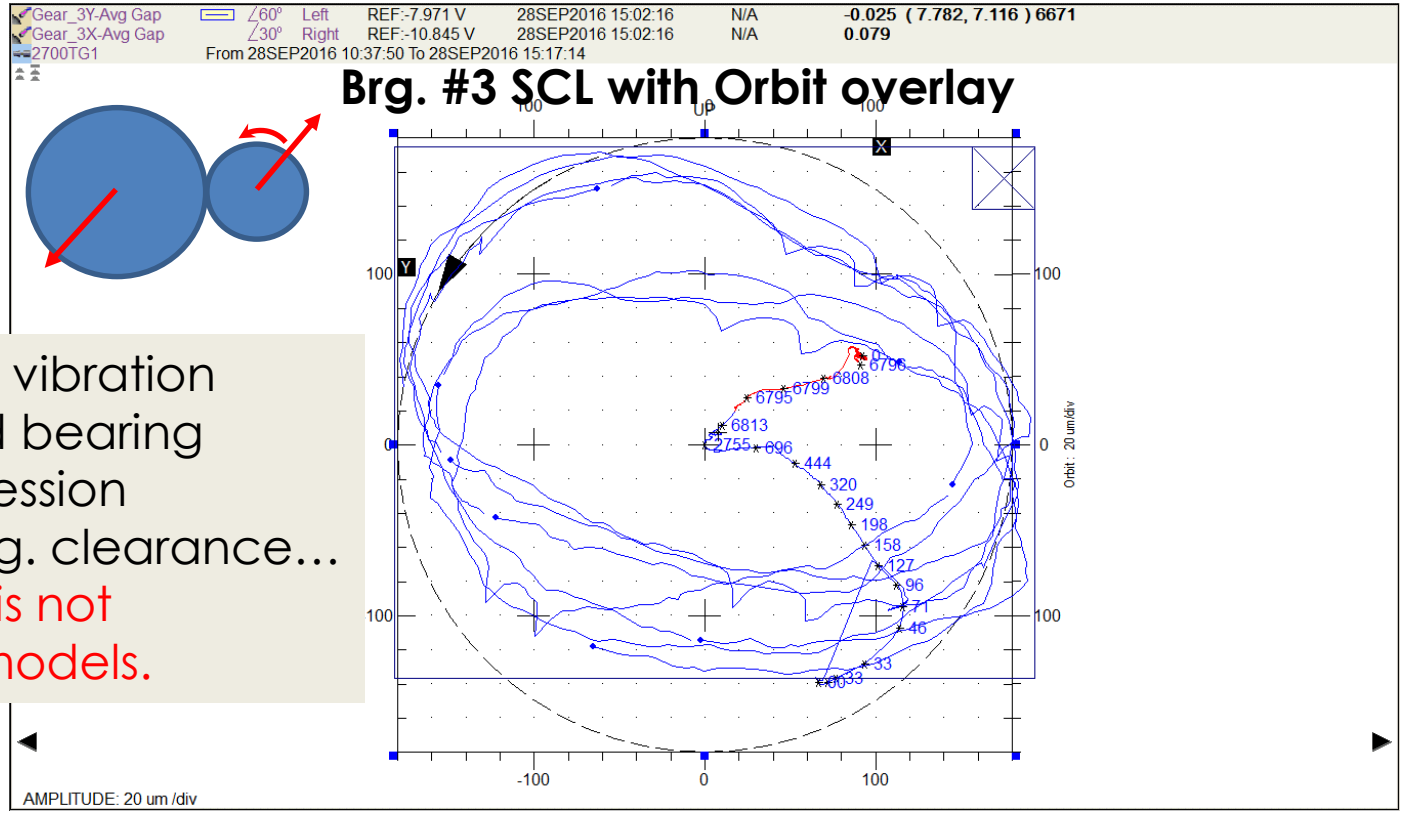
Same phenomenon, but generator was not excited during test.

Hyp. #2: Torsional excitation from generator

- Torsional measurements are not confirming presence of generator pole pass frequency alias.
- From casing vibration, the excited frequency is not matching generator pole pass frequency (4X of LSS)
- The ~0.9X of HSS activity was present for historical shutdown, the generator was not excited.

Hypothesis #2 – not probable

Hyp. #3: Perhaps fluid induced instability?



- Subsynchronous vibration
- In poorly loaded bearing
- Forward in precession
- Following the brg. clearance…

But the frequency is not matching known models.

Hyp. #3: Perhaps fluid induced instability?

- With the exception of average fluid velocity, typically near 0.5X, the shaft vibrations at brg. #3 show all classical symptoms of fluid induced instability in unloaded bearing.
- Suppose the fluid is put into motion by 1X, due to partially locked gear coupling.
- Key observation: for properly operating coupling, the vibration modes for turbine rotor and gearbox pinion should be de-coupled. Inspect the coupling.

Conclusions/Recommendations & Findings

Brg. #1 overloaded, insufficient clearance, possibly cocked	Brg. clamp found deformed, brg clearance deformed (vertical clearance 70% of nominal), and brg cocked.	
Brg. #2 reduced "crush" in housing	Brg. clamp found deformed, bearing loose in the housing.	
Asymmetric clearance in labyrinth seal at brg. #2	Likely. (Actually confirmed but in next overhaul).	
Gear coupling ST/GB is "partially locking"	Confirmed, see next slide.	

Coupling condition/problem origin

Steam leak from damaged labyrinth into coupling guard. Found 2.7% of water content in oil (at main oil tank).

Marks, flaws and… corrosion

Solution

- Turbine bearings and their clamps replaced by spares. Coupling cleaned, marks ground and polished. The teeth clearances ~ six times nominal values.
- Turbine in operation for more than year, till planned OH, with strict monitoring of oil quality. No subsynchronous excitation in operation nor in shutdowns.
- Next overhaul made with high quality standards. Rotor repaired by OEM, new bearings of original tilt-pad design, new coupling. Smooth operation since then.

Lessons confirmed and lessons learned

- All machines in the train should be properly equipped and monitored to permit diagnostics to a similar standard. If they are not… chronic problems are often developed within the insufficiently monitored machine.
- Concurrent presence of multiple malfunctions can cause symptoms not found in diagnostic manuals.
- Apparently, partial locking of the gear coupling can cause modification of fluid induced instability to frequencies approaching 1X. Added to knowledge book, more occurrences needed to confirm.